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# Conductive, transparent and low emissivity coatings of aluminum doped zinc oxide produced by magnetron sputtering

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## 1. Introduction

Making transparent and conductive interconnects on surfaces is a must for a large number of applications (solar cells, architectural and automotive windows, liquid crystal displays and light emitting diodes) [1, 2]. The search for optimal materials has led to indium tin oxide (ITO). Since the abundance of indium is limited and the consumption is steadily increasing, an extensive worldwide-research for alternative materials is going on for more than one decade. Zinc is 1000 times more abundant than indium and aluminum is the most abundant metal. Zinc oxide is transparent and easy to produce but doping with metals is necessary to make it conductive, with Al as one of the best choices. Physical vapor deposition (molecular beam epitaxy, pulsed laser deposition or magnetron sputtering), chemical vapor deposition (at high temperature, metal organic or atomic layer) and chemical methods (spin coated or solution process) have been investigated as candidates to deposit aluminum doped ZnO (AZO) [1]. When ITO was developed the magnetron sputtering turned out to be one of the most efficient methods for deposition. The main reason is that plasma provides energetic species that can dissociate the oxygen and assist the growth of crystalline films at high deposition rate and large surface coverage. Nowadays, large substrates are coated with ITO in scanning (more than 15 m<sup>2</sup> glass) or roll-to-roll (heat sensitive polymers) configurations. Consequently, the easiest way to reduce the cost will be to replace the ITO with a cheaper material. The resistivity of ITO used now is 10<sup>-4</sup> Ω cm for large substrates, while that of ZnO doped with aluminum or gallium is five times higher, with a record-low value of 2×10<sup>-4</sup> Ω cm, only for very

small areas near the edge of the substrate [3]. This effect was observed since '98 and has been associated with energetic negative ions of oxygen [3,4]. The aim of this work is to review the current status in AZO deposition by magnetron plasma sputtering and present new results on film properties at low pressure, a discharge regime that can reveal useful information about film growth.

## 2. Experimental results

The AZO films are deposited in a large sputtering chamber that can accommodate 8 samples (1×5 cm) on a rotating stage. The sputtering cathode was operated in RF (13.56 MHz) using a 2 inch target (Kurt Lesker) of ZnO doped with 2% of aluminum. The base pressure was below 10<sup>-6</sup> Torr, the target was pre-sputtered for 30 min and then the samples were positioned, one by one, under the cathode by changing the Ar gas pressure,  $p$ , and the target to substrate distance,  $z$ , for a deposition time of one hour. No additional substrate heating was provided except for that resulted from plasma. Optical emission and Langmuir probes were available for plasma diagnostics. The sheet resistance, optical transmittance and film thickness were measured with a spatial resolution of 1 mm along the 5 cm long sample (soda lime glass) for different discharge powers,  $P_{RF}$ , pressures and target to substrate distances. Smaller samples of 3×3 mm were cut out from the large sample to measure the resistivity, XRD pattern, carrier concentration and charge mobility. The sheath resistance along the 5 cm substrate ( $r=0$  at the center) is presented in Fig. 1 for  $z=4$  and 6 cm,  $p=1.4$  mTorr,  $P_{RF}=20$ W and 1 h deposition time. The two humps correlated with the erosion tracks have merged in a single one by increasing the distance with 2 cm

while the sheet resistance was four orders of magnitude different for  $r=25$  mm. The radial distribution of the film thickness for different  $p$  is

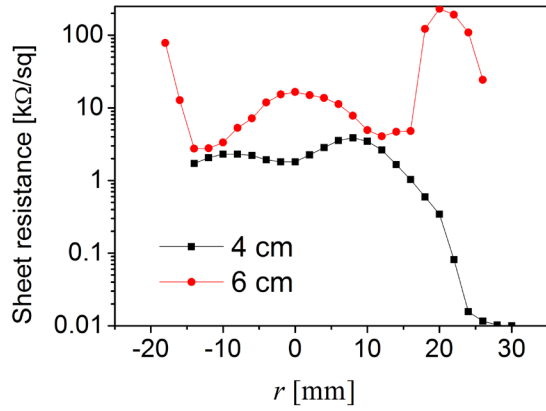


Fig. 1 Radial dependence, sheet resistance,  $p=1.4$  mTorr.

presented in Fig. 2 where one can see a considerable increase only by increasing the pressure from 1.4 to 3 mTorr ( $P_{RF}=20$ W). The same measurement performed at  $z=6$  cm revealed a similar behavior. The average transmittance at 1.4 and 3 mTorr for  $z=4$  cm and  $P_{RF}=20$ W is presented in Fig. 3. While all values were above 87% the influence of the erosion tracks can be noticed for  $p=3$  mTorr. These measurements are pointing at the importance of being able to correlate the film growth with spatially resolved

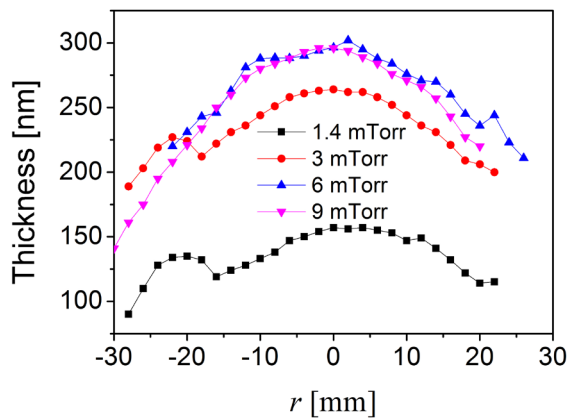


Fig. 2 Film thickness for different pressures.

plasma parameters. For example, while the film thickness and transmittance do not change significantly, a slight change in  $z$  and in pressure gives very large variations in sheet resistance. Up to date, negative ions of oxygen assisting the film growth with energies above 100 eV and also no uniform of oxygen concentration correlated with

the erosion tracks are regarded as responsible for poor film properties [2, 3]. Several reports have also presented the possibility to reduce the

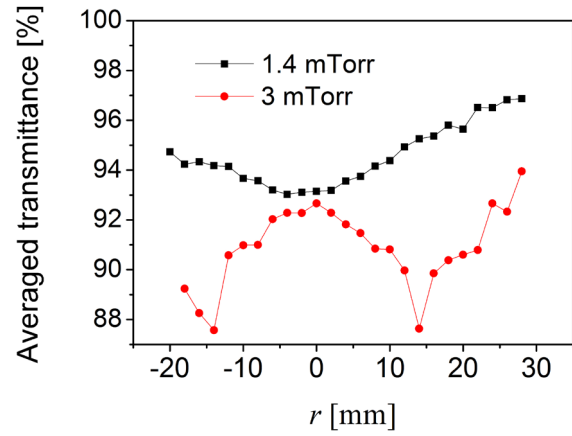


Fig. 3 Averaged transmittance,  $P_{RF}=20$  W.

negative ion influence [5]. This work shows that high spatial resolution measurements can offer a possibility to understand why the sheath resistance can change with more than two orders of magnitude in a span of only 10 mm over the sample surface. At the same time a slight change in pressure, from 1.4 to 3 mTorr has a significant effect on plasma and consequently in the film thickness and properties. Detailed surface analysis of the AZO films has been performed by XPS, XRD, TOF-SIMS and SEM and will be presented during the conference [6].

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